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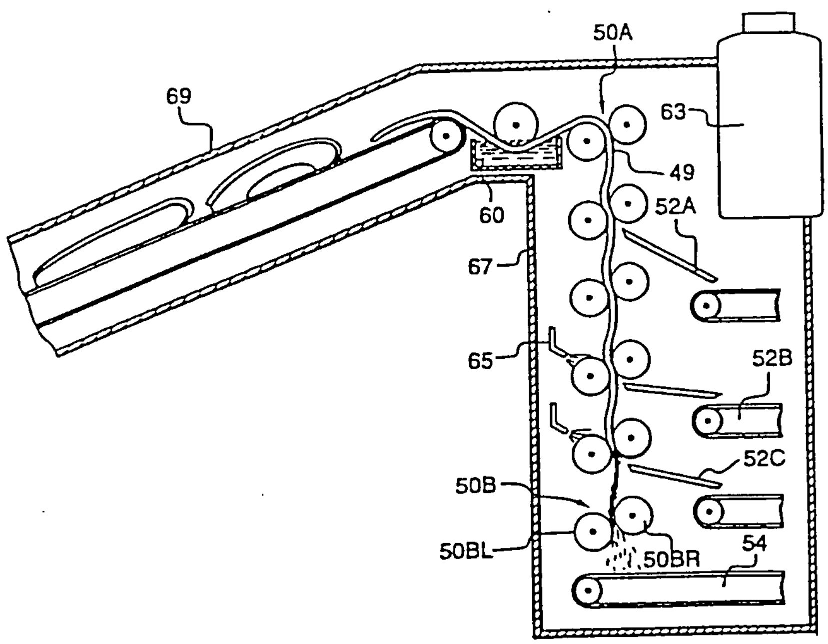

(57) Abstract

Old tires are cut into strips (49), cryogenically cooled in liquid nitrogen (60) to make the rubber brittle, and the frozen strips fed through a pair of pinch rollers (30A). One of the rollers has a grooved and knurled surface. The rollers are pushed together by hydraulic rams; the pinch force is large enough to shatter the surface of the rubber, but small enough to leave the bulk of the strip intact, and the pinch force remains the same even if the thickness of the strip varies. The strip passes progressively through successive pairs of rollers, each time the surface of the strip is shattered and the fragments fall clear. With this treatment, the steel wires and textile cords in the tire separate or delaminate very easily, and without being crushed or damaged. All the components of the material composite are recoved and separated for recycling. The rubber crumb thus separated is treated with a suitable chemical treatment for breaking down the molecular cross-links, mixed with plastic material and then repolymerised.

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CRYOGENIC PROCESSING OF USED TIRES AND OTHER MATERIALS

This invention relates to the processing of worn rubber tires, both in order to alleviate the disposal of the same as garbage, and in order to enable the recycling of the materials of the tire. The technology as described herein is not however limited in its applicability only to tires, but encompasses the processing of other items that contain different materials that are difficult to separate by conventional methods.

BACKGROUND TO THE INVENTION

Automotive tires include in their structure the following types of materials: the bulk rubber of the treads and sidewalls; the butyl rubber lining on the inside of the tire; steel wires, arranged as plies or layers embedded in a rubber carcase; hardened steel wires in the bead or rim of the tire; and textile cords, also arranged in plies or layers. Often, four different types of rubber are present: the tread rubber, the carcase rubber, the side-wall rubber, and the butyl lining rubber. The materials have value as materials that are suitable for recycling into fresh products, but only if the materials can be well separated from each other.

For example, textile cords with portions of rubber and wire still adhering thereto lose much of their recycle value, as compared with textile cords that are clean and intact. The textile cords (of nylon, polyester, etc) are valuable for recycling insofar as the cords are whole: the cords have little value if pounded to a "fluff" consistency.

The rubber from used tires, when ground into small granules (crumb), has good recycle value, but only if the crumb is clear of pieces of cord and metal. (Also, if the butyl rubber can be separated from the main bulk of the rubber, the value of the crumb is enhanced.)

Steel and hardened steel in the tires has recycle value, provided the metal is in the form of wire: the value is much reduced if the metal is reduced to granules or cuttings, and is reduced if the metal has pieces of rubber still adhering to it.

The conventional technologies for breaking down used tires are of two types: shredding, and hammering. In the shredding or cutting processes, the tire is chopped into progressively smaller pieces by heavy duty knife blades. The drawbacks to this process are: that the knives have only a short service life because of the metal present in the tires; that the chopped pieces of the tire, though small, are not separated into the different materials, and separation requires further processing; and that the equipment requires an expensive permanent establishment, and consumes a good deal of power to drive the shredding knives.

In fact, it may be regarded that the shredding procedures are really only useful in chopping the tires into small pieces (eg 5 cm x 5 cm) whereby the shredded tires do not take up so much room in the landfill, or are easy to incinerate. Shredding hardly facilitates recycling. The shredding processes are generally carried out with the tires at ambient temperatures.

The shredding processes have been taken further, and combined with granulating. Basically, this

involves chopping the tire into smaller and smaller chips. The chips are screened between stages as to size, and passed through magnetic separators, cyclones, etc for separation of the metal and textile cords from the rubber. It is possible to achieve fine grains of relatively clean rubber by this process, which is a valuable product, but the metal also is chopped into fine filings, which renders the metal of little value, and the textile cords are chopped to a fluff consistency. In addition, large quantities of energy are required. Also, the cutter blades quickly wear out; in fact it is often necessary to remove the bead sections of the tire, which contain the hardened bead wires, from the tires as a separate procedure before shredding.

In the conventional hammering or flailing processes, the tire is cut into 5 cm x 5 cm chips and taken down to cryogenic temperatures by immersing the chips in liquid nitrogen. The rubber becomes brittle at these temperatures, and the rubber starts to crack and break up when subject to hammering. Continued pounding of the pieces of frozen tire by hammers can lead to quite good separation of the material components.

Again, the hammering process requires equipment that is large and expensive. Also, large amounts of power are required to drive the hammers. This power is dissipated as heat as a consequence of the hammering process; and large amounts of heat mean that correspondingly large quantities of liquid nitrogen are required to keep the rubber cold enough to remain brittle.

BASIC FEATURES OF THE INVENTION

The invention consists in an apparatus for breaking down pieces of material such as old tires. The invention is for use with materials of the kind which become brittle at cryogenic temperatures.

The apparatus includes a pair of platens, and a means for forcefully urging the platens together to form a nip or pinch. The platens are set in motion, whereby the nip or pinch draws the material into and through the nip.

In the invention, the surface of at least one of the platens is nodulated. The surface is characterised as nodulated, in the context of the invention, when the surface is not smooth, but when the surface has nodules, having substantial crests and troughs. Preferably, the height or depth between the crests and troughs is at least of the order of one-tenth of a millimetre.

It is the fact that the surface of the platen is nodulated that allows the platen to assault just the surface of the material, using a relatively light compression or pinch force. To achieve this surface-only assault, it is necessary to concentrate the pinch force into the points or crests. This concentration will not occur if the platen is too smooth, i.e. if the points or crests are too small. If the surface of the platen is smoother than the above crest-to-trough height of 0.1 mm, the pinch force will not be properly concentrated into the surface of the material.

In the invention, the crests and troughs of the nodulated surface of the platen must be pitched neither too close together, nor too far apart. If the crests were to be too close together, the surface would appear, to the piece of the material actually present in the nip or pinch, to be smooth, and the characteristic surface-assault would not take place. From this standpoint, preferably the pitch of the

crests should be at least of the order of one-tenth of a millimetre apart.

Similarly, the crests and troughs of the nodulations must not be too far apart, whereby the surface of the platen would be not so much nodulated, as contoured; in that case, the material would start to bend bodily to conform to the contours, and the effect of assaulting the surface with points would be lost. From this standpoint, the pitch of the crests, ie the distance between adjacent crests, should be less than the thickness of the piece of material passing through the nip or pinch of the platens.

In the invention, it is not necessary that the above dimensions of crests and troughs should apply over the whole surface of the platen. It is beneficial, sometimes, to provide reliefs in the surface, in the form of cut-away grooves, being grooves of much larger depth and width than the crests and troughs of the nodulations. Such grooves serve to permit debris breaking from the surface to escape, and serve also to allow the required concentration of force into the points to be achieved while keeping the overall pinch-force between the platens at a low value. Of course, less of the surface of the material will be broken when the surface of the platen is provided with such relief-grooves, but the un-broken areas will be picked up on the next pass.

A preferred manner of creating a nodulated surface on the platen is to machine criss-cross grooves on the platen, the grooves being of triangular form, whereby the surface of the platen acquires regularly-spaced rows of small pyramids. If the material of the platen so allows, the pyramids may be created by knurling, i.e. by pressing or rolling the surface with a suitable knurling tool.. Rolling or knurling cannot be carried out on some materials, and if the material from which the platen is made does not allow knurling, the pyramids may be created by means of a cutting tool.

The nodulated surface of the platen may be formed on a separate piece from the roller itself: when the platen is a cylindrical roller, for example, the nodulations may be formed on a replaceable sleeve.

The pyramids are pointed; when the points become dulled, following a period of use, the surface should be replaced, re-machined, or treated in some suitable way, to restore the sharpness of the points.

As has been described, the platens have a nodulated surface, whereby the pinch-force between the platens is concentrated into the crests of the nodulations, so as to assault just the surface of the piece of material passing through. It is also important to ensure that the speed of the piece of material in passing through the nip or pinch of the platens is neither too fast nor too slow.

In considering the optimum speed of passage of the piece of material through the nip or pinch, it should be borne in mind that cracks spread through a brittle material (including cryogenically-cooled rubber) at a characteristic speed. As far as speed of the material through the nip or pinch is concerned, therefore, the speed of the material should be such that the cracks instigated by the crests of the nodulations propagate each as far as the next crest, before the material passes out from the nip or pinch zone. It may be assumed that the cracks cease propagating once the material has passed through the pinch. Therefore, the speed of the material should be slow enough that the cracks have the opportunity to spread all the way from crest to crest while passing through the nip or pinch.

Of course, the pitch of the crests is critical in determining what this optimum speed will be in a particular case.

On the other hand, once the cracks have indeed spread over the whole area between the crests of the nodulations, any continuing compression of the material between the platens serves now to dissipate the pinch-force into the bulk of the material.

As described, the present invention seeks to break down the surface of the material, and in effect to delaminate the material, progressively peeling off the surface. In contrast to the invention, it is well-known to be possible to cause cryogenically-cooled rubber to break down by simple, brute-force, bulk crushing. However, this requires much more force, more energy, more cooling, etc.

If the speed of the material through the pinch is too slow, some of the pinch-force is wasted in that no further surface cracking would take place, but instead the pinch force, and the energy associated with that force, would be dissipated into the bulk of the material. In other words, if the speed of the material through the pinch is too slow, no further surface cracking takes place, but rather energy is wasted by being dissipated into the bulk of the material, which heats the material, and which therefore requires more liquid nitrogen to keep the material cool.

The ideal speed of the material through the nip or pinch is the speed at which the cracks emanating from the points just meet up with each other: too fast, and the surface is not fractured through; too slow, and more than the minimum of energy is dissipated in the material.

In fact, it has been found that the sound made by the piece of material passing through the nip or pinch is highly characteristic of the type of fracturing occurring. When the speed is right, ie when the fracturing of the surface is right, the sound is a crisp sharp crackling sound, whereas when the speed is too fast, the sound becomes a harsh tearing sound, and when the speed is too slow, the sound becomes a screeching crushing sound.

When the sound is right, and the speed is right, the number of times the material must be passed through the platens to break it down is a minimum. When the speed is right, the efficiency of breakdown – that is to say, the amount of energy used to break down a given amount of material – is optimised. It quickly becomes apparent to the operator of the apparatus as described herein that the sound indicates whether the speed is right, and that by adjusting the speed until the process "sounds right", he will have accurately adjusted the apparatus to the optimum mode of fracturing.

In a particular case, it was found that the speed of the material through the nip or pinch should be between 4 and 13 cm/sec, with the optimum speed being 8 to 10 cm/sec.

As described, the process of breaking down the material lies in instigating fractures, which emanate from the points of the nodulations on the surface of the platen. The process does not depend on pounding or hammering the surface while at cryogenic temperatures, in the prior art sense, where prior art processes for breaking down cold rubber have involved the use of hammer-mills and flails.

However, in the process as described, it should not be understood that the crushing action is

entirely free from vibration, and perhaps such vibration can be likened to hammer blows. The vibration takes the form of in-out motion of the platens relative to each other, and takes the form also of torsional vibration in the drive to the platens. It would be very expensive to eliminate such vibration, and it has not been found necessary to do so; it may be, in fact, that the vibration is playing a part in propagating the cracks away from the points, and thus increasing efficiency. This type of vibration, however, should be clearly contrasted with the gross hammering, flailing, or pounding action of the prior art processes, which is a much more deliberate action, and which simply serves to feed wasteful energy into the bulk of the material.

Preferably, at the point of nip or pinch the platens should have the same peripheral speed. This can be done by driving both platens at the appropriate speeds, or by driving just one platen, the motion of the other being picked up from the material passing through the nip or pinch.

If there were to be relative motion between the platens – if the platens were to be driven at different peripheral speeds, for example – it might be surmised that there would be a benefit in that some shearing of the material might take place, which would assist in the de-lamination. However, it is suggested that the sliding friction resulting from the relative motion, which inevitably would put heat energy into the material, would cause more inefficiency than would be gained.

On the other hand, some arrangements of platens or rollers can be envisaged in which there is just a little relative motion between them, and such relative motion can be tolerated if it introduces only a little inefficiency.

In fact, a lateral shaking motion may be included in one of the nips or pinches through which the material passes: this shaking motion serves to dislodge and to free any pieces of cracked and broken rubber that may still be adhering. In fact, when tire pieces are passed between rollers that shake from side to side, it is found that the metal wires and the textile fibres of the tires emerge generally cleaner; cleaner, that is, from the standpoint of small particles of rubber still adhering thereto. These rollers that shake from side to side may be pressed together with less pinch-force than the main sets of rollers.

Recycled rubber has many uses, but one limitation of recycled rubber is that the rubber is vulcanised, which makes the rubber highly inert to chemical change. Therefore, while it is easy to use conventional recycled rubber in cases where the recycled material need only serve as a bulk filler in low grade composites, there is a far greater potential use for recycled rubber if the rubber could be made suitable for combining chemically, or re-polymerising, with virgin plastic material.

Such processes have in fact been developed. It has been proposed, for example, to treat the rubber crumb with a halogen, in order to affect the surface of the crumb, whereby the crumb can be caused to adhere by chemical combination during polymerisation of the plastic material, and the resulting combined material is much stronger than composites where the rubber was just an inert filler. However, such processes have not reached commercial use because it has not been possible to provide recycled rubber of the right crumb size and consistency, and to the right standards of cleanliness. If any of the butyl rubber, for example, is present, even in tiny quantities, the chemical bonding becomes much more difficult.

The rubber crumb produced as described, however, is, or can be, free from butyl rubber to a very high degree. Therefore, these processes which aim to make crumbs of vulcanised rubber combine or bond chemically to other polymers, can, with the invention, become viable, insofar as the invention can be used to create clean, consistent crumb.

It may be noted, in fact, that the granules of crumb from the prior art processes, having been pounded and hammered, tended to be more or less spherical. The invention involves basically only a cracking operation to separate the granules, whereby the granules have a much more irregular, jagged shape than the prior art granules. Therfore, the surface area of the granules produced by the invention tends to be relatively high. The halogen treatment process as described treats the surface of the granule, and so the fact that the granules, as produced by the invention, have a large surface area is an added advantage, in addition to the economy with which the granules can be produced.

By the use of the features of the invention, tires may be broken down with a minimum of capital equipment. The machinery required in fact can be portable. With conventional tire processing systems, a town might produce say 30 truckloads of worn tires per month, which have to be transported to a large tire processing depot: with the invention, a portable tire processing plant can visit the town periodically, and process the old tires in situ. The separated recyclable materials, in the form of crumb etc, still have to be transported to a central depot, but now the same materials typically only comprise one single truckload per month.

It will be understood also that the smaller the size of the plant, or at least the smaller the number of, and size of, the rollers, the less the amount of liquid nitrogen required to cool the rollers down to cryogenic temperatures.

With the invention, pre-shredding is not required, although it is contemplated that the tire may be separated into side-walls and tread prior to processing, by a simple cutting operation.

It is an aim of the invention that all components of the tire emerge in a well-separated, clean, manner, which allows all the components to be as valuable as possible to recyclers.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENT

By way of further explanation of the invention, exemplary embodiments of the invention will now be described with reference to the accompanying drawings, in which:

Fig 1 is a pictorial view of a pair of pinch rollers, and shows a piece of a tire tread being fed between the rollers, in accordance with the invention;

Fig 2 is a plan view of the pair of rollers of Fig 1;

Fig 3 is a close-up of a portion of one of the rollers of Fig 2;

Fig 4 is a schematic diagram of a layout of an apparatus which embodies the invention, in which

used tires are being processed;

Fig 5 is a diagram of another apparatus which embodies the invention, and which is used in the processing of whole tires;

Fig 6 is a view corresponding to Fig 4, showing a different arrangement of rollers;

Fig 7 is a view of another roller arrangement that may be used in the invention.

The apparatuses and procedures as shown in the accompanying drawings and described below are examples which embody the invention. It should be noted that the scope of the invention is defined by the accompanying claims, and not necessarily by specific features of exemplary embodiments.

Fig 1 shows a piece 20 of a tire being fed between a pair of pinch rollers 23,25. The piece of the tire may be a portion of the tread or the side wall of the tire.

For ease of feeding the pieces through the pinch rollers, prior to passing through the pinch rollers the tire is fed through a cutter which slices the sidewalls from the tread. Cutting the tire into pieces is an expensive step, requiring a special cutting station, and a good deal of service attention. As is described below, in the invention it is possible to eliminate the pre-cutting of the tire into pieces and to process the whole tire as a unit, the sidewalls and tread still together.

The piece 20 is a portion of the tire that can be described as a strip, in that the piece is relatively large as regards its length and planar extent, and relatively small as regards its thickness.

The piece or strip 20 is taken down to cryogenic temperatures by cooling the piece with liquid nitrogen. Rubber becomes as brittle as glass at these low temperatures. To maintain the low temperatures, liquid nitrogen is sprayed, or otherwise applied, onto the piece 20 as it continues through the rollers, via the nozzles 27.

Preferably, the strips 20 are submerged into a bath of liquid nitrogen. The more rapidly the rubber is cooled, the more lilely it is that the crystals of rubber that form will be unstable, and will be the more readily broken when cracks are instigated in the material. Once the material has been thoroughly cooled, it may be kept cold by spraying liquid nitrogen thereon.

As the piece or strip 20 passes through the rollers, heat is generated due to the material being crushed. Liquid nitrogen is available in sufficient quantities to ensure that the piece remains cryogenic, ie to ensure the rubber of the tire remains cold enough that the rubber stays as brittle as glass.

Fig 2 is a plan view of the strip 20 passing through the pair of pinch rollers 23,25. The roller 23 is coupled to an electric motor 29, and is driven in rotation. In the example, the speed of rotation is 6.5 rpm. As to the rollers 23,25, they are 25 cm in diameter, and 30 cm in axial length. The spindle 30 of the driven roller 23 is mounted in bearings 32 which are fixed in relation to the apparatus frame 34.

The manner in which the strip passes through the rollers may be described as a comparatively smooth and gentle extrusion process, rather than a simple brute-force crushing process. As such, the strip that emerges from the rollers still retains its structural integrity as a coherent strip.

The roller 25 is not driven, but is free to rotate, being mounted in bearings 36. The bearings 36 are movable (ie slidable) under the action of hydraulic rams 38. The rams 38 are fed with hydraulic pressure from a pump 40, which is under the control of a pressure regulator 43.

The bearings 32,36 are subject to shock loads, and have to operate in reduced temperatures (although of course the bearings are positioned so as not to be immersed in the liquid nitrogen). The bearings should be over-engineered for a long service life, but still should be made easily replaceable.

It is not intended that the rollers must necessarily be cylindrical, and parallel. The rollers may be set at different angles, or may be convex/ concave, etc. Both rollers may be driven, or just one roller may be driven, the other being given motion by the passage of the strip between the rollers.

It will be noted that during processing the contact force between the rollers 23,25 remains substantially constant because of the hydraulic rams 38, irrespective of the thickness of the strip 20 passing through. Thus, when no piece is present between the rollers the rollers are pressed into direct contact with each other (actually, a travel stop may be incorporated to prevent the rollers from actually touching when no piece is present).

When the piece passes through the pinch, the force on the rollers starts to increase; the hydraulic pressure does not increase, however, and so the roller moves back until the extra force has been shed. Thus the pinch of the rollers is not controlled by the setting of the distance apart of the rollers, but rather by the force urging the rollers together. That is to say, the pinch of the rollers is "fixed-force", rather than "fixed-distance". The engineer can select the most appropriate value for the hydraulic pressure, to give the appropriate pinch force for best processing results.

The roller 23 is formed with grooves 45. The grooves 45 are cut into the cylindrical face of the roller 23, leaving protruding lands 47 between the grooves. The other roller 25 has no grooves. The surfaces of the rollers 23,25 are formed with small criss-cross grooves, which leaves the surface with many sharp points, spaced apart in regular arrangement. Such a surface texture may be produced by a rolling process (knurling) or by cutting the grooves. In fact, since the rollers will generally be of stainless steel (because of stainless steel's good low-temperature properties) and since it is difficult to condition the surface of stainless steel by rolling, forming the grooves and points by cutting is preferred. The surface, textured with many sharp points, is referred to herein as a knurled surface, even when produced by cutting.

The surface of the roller 25 preferably is knurled, as is the surface of the lands 47. The sharp points of the knurling assists in ensuring that the piece is efficiently nipped upon approaching and passing into the pinch between the rollers. The sharp points assist in breaking up the layers of the tire, as explained.

The frozen piece 20, in passing between the rollers 23,25 is acted upon by the grooves 45, or rather

by the lands 47 between the grooves. The piece being fed through should be oriented with the outside or tread portion of the tire, ie the thick rubber portion, towards the grooves; leaving the inner portion of the tread (which includes the butyl rubber) in contact with the plain roller 25.

In fact, it is in the nature of the tire material that the tread rubber separates first, rather than the fact that one roller is nodulated and the other is smooth. The tread rubber is the most embrittled by cryogenic cooling, and breaks away first, and the butyl rubber is last, even if both rollers are equally nodulated.

With the provision of the grooves in the rollers, it has been found that the compressive force acting in the pinch between the rollers concentrates the action of the rollers into the surface portion of the strip that lies directly in contact with the grooves. In the surface layer of the strip being processed, ie the layer immediately affected by the assault, the rubber shatters; but in the bulk of the material thickness of the strip, the forces from the rollers are spread out and dissipated into the bulk of the material, and the tendency in the layers of the strip away from the immediate surface zone in contact with the grooves, is for the material merely to crack, rather than to shatter.

It has been found that the many sharp points on the lands of the roller 23 and on the surface of the roller 25 are important in achieving a good breakdown and separation of the materials. It may be regarded that the sharp points serve as fracture initiators. By concentrating the assault force into sharp points, the surface of the composite material is subjected to very high local stresses, which cannot be dissipated because the material is embrittled, and the material directly under the points therefore shatters. Deeper into the bulk thickness of the material, the effect of the points can and does become dissipated, whereby the effect changes from shattering at the surface to mere cracking in the bulk interior.

As a result, in passing between the nodulated rollers 23,25, the bulk of the piece 20 develops cracks but remains largely intact, whereas the surface layer of the piece is cracked and shattered, and is broken up into fragments.

It is recognised that this is exactly the mode of break-up that is required: the surface layer of the tire strip is shattered, and falls away, leaving the bulk of the strip almost unaffected, and still coherent.

The parameters that lead to this kind of break-up should be controlled. For example, if the pinch force is too strong, it is as if the whole material is being crushed, and the preferred break-up of the surface over the bulk would be lost.

For rollers of about 25 cm diameter and 30 cm width, the following values of the parameters should be observed:

speed of rotation: 3.5 to 15 rpm, preferred 6.5 rpm;
torque: preferred 1100 N-m;
pinch force: 18 to 50 kN, preferred 32 kN;
knurl spacing: right pyramids in a diamond pattern, 2 mm diagonally across the diamond, giving a density of about 50 points per sq cm;
point depth: 1.1 mm from base of groove to vertex;

grooves and lands: grooves 4.7 mm wide, tapered inwards, and 4.7 mm deep; lands 6.4 mm wide.

Other pairs of rollers are provided, and the strip is fed progressively to each in turn (or the strip may be passed repeatedly through the rollers 23,25). At each pass the groove-side surface layer of the strip is shattered, is converted into small fragments, and falls away.

Soon, all the rubber on the outside of the tire piece is removed, whereby the layer of wires which make up the steel belt of the tire become exposed. It is found that when these wires are exposed, they too simply fall clear of the strip.

The wires break clear of the embedding rubber as they come under the grooves. The wires emerge as whole wires; usually indeed the wires appear to be hardly damaged. There is very little tendency for the wires to become mangled, crushed, twisted, or otherwise distorted. Sometimes, however, old tires have been compressed into bales, and this can cause the wires to be mangled: it has been found, however, that tires that have been baled, even though distorted into awkward shapes, can be processed with the apparatus as described.

Even when the steel wires have fallen clear, still the piece 20 remains as a coherent strip. In some tires, there may be more than one layer of wires, and, if the strip is a piece of tire side-wall, the bead or rim of the tire contains some wires (and the bead wires can be especially tough and hard). In the apparatus as described, it does not matter how tough the steel is: the rubber is broken away from the steel in a manner that does not affect the steel, and does not require the steel to be cut.

The tire also will usually contain one or more layers of textile cords embedded in the tire. As processing of the piece continues, these cords hold the piece together as a coherent strip, even when the strip has been through the rollers many times, and has shed much of the thickness of its matrix of rubber. Finally, of course, the strip does disintegrate, and the remaining material passes out in more or less granular form.

These multiple stages are illustrated in Fig 4. In Fig 4, the strip 49 is fed into the first pair 50A of a cascade of pinch-pairs of rollers. Chutes 52A,52B are provided for collecting material that falls off the strip 49. In fact, the chute 52A can be arranged to touch, and to scrape against, the strip 49, whereby the chute can serve as a scraper to aid in the removal of the shattered surface material. As the strip progresses through the cascade, the strip becomes more fragile and starts to lose coherence, and so the lower chutes cannot be allowed to touch or scrape the strip.

The material entering the first chutes and conveyor 52A is rubber crumb from the outer tread. The material entering the chutes and conveyor 52B is the steel wires (mixed, inevitably, with more rubber crumb). The material entering chute 52C is the textile cords, again mixed with rubber crumb.

By the time the strip reaches the lowest pinch pair 50B of rollers, all coherence in the strip is gone, and the material comprises just unconnected particles and shards.

The strip, in passing through the pinch rollers, basically retains coherence so long as some of the textile cords are still present in the strip. It happens that, with many types of tire, by the time the last

textile cords are gone, the remaining rubber is the butyl rubber, which falls from the final pair of rollers onto the conveyor 54. Butyl scrap may be regarded as a contaminant, which detracts from the value of the crumb. Once the butyl rubber is allowed to mix with the other rubber, as happens in the other tire processing systems for example, the butyl really cannot be separated.

As the strip continues progressively through the pairs of rollers, and loses thickness, the design engineer should see to it that the nodulations in the rollers become progressively smaller. It is suggested that the pitch of the grooves should be of about the same dimension as the thickness of the strip; as the thickness gets smaller, the pitch of the grooves should be smaller.

The final pairs of rollers in fact do not have grooves formed therein, but are just knurled. As the thickness of the strip gets smaller, the alternating points and spaces of the knurl take over with the same effect the grooves had at the larger thicknesses, ie of concentrating the shattering action at the surface, and leaving the bulk thickness of the material (or such bulk thickness as still remains) intact. Both rollers may be knurled, or one may be left smooth. In fact, by the final rollers, the greater thickness of the remaining rubber is not on the tread side of the tire strip, but is the rubber on the inside (left side in Fig 4) of the strip, and it may be the left roller 50BL which is knurled, while the right roller 50BR is left plain.

The surface of the rubber that is subjected to the shattering is the surface that comes into contact with the grooves. The rubber on the other side, like the bulk of the strip, remains largely unaffected. Thus, the butyl rubber on the inside of the tire piece can be saved until last, provided the strip is always presented to the rollers with the inside of the piece away from the grooves. This is why it is important for the strip to remain coherent for as long as possible. (With some types of tire, as mentioned, the order of separation is inherent in the tire itself, and the tire disintegrates from the tread-side inwards, even if fed through the rollers the wrong way round.)

The fact that the strip remains structurally coherent means that no other means of conveying the piece from roller to roller need be provided.

The effect that is sought, right through the processing of the piece through the multiple pairs of rollers, is to shatter the rubber, and break the rubber clear of the cords and wires, while leaving the cords and wires themselves as unaffected as possible.

It may be noted that the textile cords do not become brittle at cryogenic temperatures, like the rubber. Manipulation of the frozen strip will crack and shatter the rubber, but the cords remain flexible enough to simply twist and bend without being torn and damaged. As may be seen in Fig 4, the lines-of-pinch of the pairs of rollers are not aligned with the direction of travel of the strip; therefore, the strip is caused to flex as it passes from roller to roller.

In Fig 6, the strip is bent as it passes between stages, which is an alternative low-energy manner of flexing the strip. In fact, in Fig 6, the delamination of the rubber strip is in distinct stages. In the first stage 80, comprising two pinched-pairs of rollers, the tread rubber is separated. The rubber then passes through a second stage series 83 of rollers that cause flexure and bending, and consequent cracking right through the strip. The rubber then passes through a third stage 85, where the rollers break down the carcase of the tire, allowing the wires that form the plies of the tire to separate from

the carcase rubber. Shaker rollers 87 are placed at strategic locations to assist in releasing the broken pieces from the strip. The fourth stage 89 rollers separate the remaining carcase rubber from the textile cords, and from the butyl rubber. The nodulations on the surfaces of the rollers become progressively more dense through the stages, as the thickness of the strip decreases.

Once the component materials fall clear of the strip, and enter the chutes and conveyors, granules of the rubber may still be adhering to the wires and cords. These granules can be separated by suitable carding operations, ie by rubbing the cords and wires between flat plates, eg with an orbital motion, or by flexing the cords and wires around tight bends. The rubber should continue at cryogenic temperatures to make this separation effective.

Another measure that may be taken to assist in separating any last rubber granules still clinging to the wires and cords is to provide for one of the rollers of the pair to oscillate in the axial direction. Such lateral motion of the roller produces very vigorous manipulation of the wires and cords, which efficiently breaks off the rubber; though at the expense of increased mechanical complexity of the apparatus. Also, as mentioned, the structural coherence of the strip should be retained for as long as possible.

For best results it has been found that the grooves should be spaced apart at about the same pitch as the thickness of the strip passing through the rollers. The grooves may be formed as simple cylindrical grooves, which may be cut on a lathe. The grooves should be deep enough that the materials do not bottom in the grooves; that is to say, the grooves should provide "somewhere to go" for the material that shatters and detaches from the strip. This is one of the key factors in ensuring the surface is broken up to a much greater extent than the bulk of the material. Thus the grooves should be about as deep as they are wide.

It is not essential that the grooves be cylindrical from the standpoint of rubber-shattering performance. It is just that cylindrical grooves are easier to cut than other configurations. The grooves might be helical, for example, or axial, or a combination. It is also contemplated that the effect of alternating lands and grooves can be achieved by adding studs or spikes over the cylindrical surface of the roller.

It is not the intention that the material composite should be broken in a single pass through one pair of pinch rollers. It is the intention to achieve a differential break-up of the composite, in that in each pass only the surface is broken and removed, exposing the next layer as the surface in turn, which, in turn, is broken up and removed. As such, the process as described is rather a process of gradual delamination than of bulk crushing.

In the system as described, the strip is subjected to slow, gentle, progressive extrusions. The system requires only a minimum energy input, and yet is able to delaminate the tire gradually, but very effectively, into its component materials.

The hydraulic pressure which controls the pinch force of the pair of rollers should be carefully controlled: if set to too high a pressure, the whole bulk of the material is assaulted, and the wires and cords start to become damaged, and the consumption of energy shoots up. On the other hand, of course the pressure should be as high as possible to keep the number of passes required (and

the number of pairs of rollers) to a minimum.

The preferred magnitude of the force is between 0.7 and 1.7 tonnes per linear cm of width of the strip of material, with an optimum force of about 1.1 tonnes per cm.

As shown in Fig 4, six pairs of rollers are provided, which is generally suitable for tires from cars and light trucks; more, or fewer, pairs may be indicated for other types of tires.

As shown in Fig 4, the pieces of the tire that are to be processed are cooled by liquid nitrogen from a reservoir bottle 63. Other baths and LN sprays 65 may be supplied from the same source.

The cascade of pairs of rollers is contained within a housing 67, which collects the still-cold nitrogen gas that boils off. The nitrogen gas is collected and fed down a tunnel 69 through which the pieces of the tire are being fed to the rollers. The cold gas assists in pre-cooling the pieces.

In the apparatus of Figs 1-4, the tires are separated from the side-walls prior to being fed to the pairs of rollers. In Fig 5, the apparatus is suitable for the processing of whole tires; that is to say, the whole tire is fed into the apparatus without being first cut into pieces.

The pairs of rollers 70,72 are mounted for rotation in bearings that permit the axles of the rollers to swing relative to the frame of the apparatus. In order to feed a tire 74 into the apparatus, the rollers 72 are swung aside, and then closed upon the tire profile, as shown. Suitable rams (not shown) act to compress the tire between the rollers 70 and the rollers 72.

In Fig 5, instead of the tire being passed from roller to roller, rather the progressive break-down of the tire material is achieved by feeding the tire 74 repeatedly through the same rollers. The surface of the tire material progressively shatters and falls clear, then the wires fall clear, then the cords fall clear, as in the previous apparatus. The tire can be expected to undergo five or six revolutions through the rollers before disintegrating, whereby each location on the tire passes through the rollers that number of times.

Hydraulic pressure in the rams is maintained throughout the processing of the tire, and keeps a constant steady force on the material.

The rollers 70 are provided with grooves, and are knurled, as previously described.

The tire 74 should be pre-frozen before being passed to the rollers, preferably by being dipped into a bath of liquid nitrogen, and a continual spray of liquid nitrogen should be maintained on the material.

It can be expected that the tire will not remain as a coherent unitary whole tire right down to the final layer of cords, and therefore the engineer will generally prefer to arrange that the larger pieces that break away as the tire disintegrates will fall into a supplementary pinch-pair of rollers (not shown) positioned to receive same, for final shattering of the remaining rubber pieces.

Because of the cryogenic temperatures, the design of the components of the apparatus should be

given special care. Ordinary steel tends to go rusty easily when very cold: this is a disadvantage because: (a) the rust flakes off, and contaminates the crumb; and (b) the rust fills up the spaces between the points of the knurls, which spoils the effect of the knurls in concentrating the assault into the surface of the material passing through. Forming, or at least facing, the rollers with stainless steel is therefore preferred.

The coefficient of thermal expansion of rubber is quite different from that of steel. The differential contraction/ expansion between the brittle rubber and the steel wires in the tire serves to assist in separating the rubber from the steel. This effect can be utilised in the system as described because the break up of the rubber is a gentle progressive delamination, rather than gross wholesale destruction.

As mentioned, the system as described is very efficient as regards energy usage. This is of course worthwhile in itself, but it should be noted that the low energy demand has an economic multiplying effect. Any mechanical energy that is fed into the material composite to break down the material is absorbed into the material in the form of heat. Thus, if a 30 kW motor is used to drive the rollers, most of the 30 kW is dissipated as heat into the material. If only a 5 kW motor can be made to achieve the same degree of breakdown of the material, only 5 kW of heat goes into the material. The material has to be kept at cryogenic temperatures, and the less the amount of heat going in, the smaller the volume of liquid nitrogen required. Where power is cheap, the difference between 30 kW and 5 kW may not amount to much in itself, but the corresponding difference in the consumption rates of (expensive) liquid nitrogen will inevitably make the savings due to energy efficiency highly worthwhile.

The invention has been described as it relates to the processing of old tires, and one particular aspect of the composite material of tires is that the material can be made to stay as a coherent strip, with the separate materials peeling themselves off in layers, right down until the strip is almost on the point of complete disintegration into crumb. However, the system of passing cryogenically-frozen material between rollers can be used, though not to such great advantage, on materials the pieces of which do not appear in the form of coherent strips. For example, the system may be used to process the crumb that is produced by the conventional shredding or chopping processes, where the rubber is chopped into small pieces, but is not separated from the steel wires and textile cords.

The invention is aimed at minimising the energy required to break down the material, by assaulting just the surface of the piece of material, and can be applied to any material that becomes brittle when cryogenically cooled, irrespective of the size and shape of the pieces of material.

Other materials besides rubber, some plastic materials for example, become brittle when cryogenically frozen. The invention may be used in the separation of glass-fibre reinforced plastic, for example, or in the separation of carbon (graphite) epoxy layered mat.

Another area in which the invention may be used is in separating plastic or rubber insulation from electrical cable. Conventionally, such separation is done by slicing most of the insulation from the metal conductor, and by burning off the remaining adhering insulation.

The invention may be used not just in the context of separating the components of composite

materials but may be used also for breaking down bulk non-composite materials into fine crumb. For example, the invention may be used in the process of preparing raw latex, prior to processing into rubber. Such raw latex often is shipped in large flat slabs of a thickness of 3 or 4 cm.

The slab is first taken down, by immersion in liquid nitrogen, to cryogenic temperatures, and then passed between pinch rollers. The rollers are provided with points or lands (nodulations), as described, whereby the assault on the latex as it passes through the pinch is concentrated in the surface layer of the slab. The surface layer then cracks, shatters, and falls away. The slab is taken progressively through sets of pinch rollers, at which the surface layer is removed each pass, until the material is gone.

Again, the principle of progressively assaulting just the surface layer, while leaving the bulk intact, is utilised. The latex slab is reduced to crumb by progressively taking layers from its surface, not by attacking its bulk. It may be pointed out again that the smaller the amount of energy that is used in breaking up the material, at cryogenic temperatures, the smaller the quantity of heat energy that has to be removed by the liquid nitrogen.

For the invention to be applicable, the material must be of the type that is brittle at cryogenic temperatures, but is resilient, ductile, flexible, and even elastomeric, at ambient temperatures. (If a material is already brittle at ambient temperature, of course there is no point taking it down to cryogenic temperatures to shatter it.) As mentioned, the material need not be composite; although it is an advantage, in the case of composite materials, that the different components usually have different responses to cooling to low temperatures, which aids in break-up and separation. In fact, the invention may be used for reducing to fine particles many organic materials that are hard to break up at ambient temperatures. For example, such items as kernels or grains of cereal crops, assuming they are not damaged by cryogenic temperatures, may be comminuted by the means as described herein.

It is contemplated within the invention that the rollers may be large or small. If of a large diameter, the rollers will easily nip or pinch the materials: the designer will prefer the rollers to be as small as possible once that requirement is met. The rougher the surface of the rollers, the smaller the roller can be, and still effectively grip or nip the material, to draw the material into the pinch.

Fig 7 shows an arrangement of rollers where several smaller rollers 90 are urged against a larger roller 92. This makes the mechanical drive arrangements simpler, since only the one large roller 92 need be driven. The smaller rollers 90 may be provided with different densities of nodulations.

It was mentioned above that the cords and wires that separate from the strip can be further separated from any pieces of rubber still adhering thereto by passing the cords and wires between plates; the plates are pressed together, e.g. by hydraulic rams, and the plates undergo relative motion, for example a relative orbital motion. It is contemplated within the invention that the rollers might even be done away with, and the whole process of separation be carried out by compressing the material composite between plates which move relatively, for example with an orbital motion. Again, the plates are grooved and knurled, in order to concentrate the shattering effects at the surface of the material.

It is recognised that the lands between the grooves, and the points of the knurls, are very important in concentrating the assault into just the surface of the material. The points of the knurls preferably should be sharp, and the efficiency of the processing can be expected to deteriorate as the points become dulled. It is suggested that the surface be re-knurled, and the points restored to sharpness, when the points have been dulled to a flat of no more than 0.5 sq mm in area.

The extent to which the surface of the material can be shattered, whilst leaving the bulk of the material untouched, depends on the nature of the protruding points. If the points are too close together, the pinch force from the rollers then becomes applied over the whole surface of the piece of tire, and the surface then is subjected to hardly any more pressure than the bulk of the piece. On the other hand, if the points are too far apart, some of the pinch force tends to be taken on the recesses between the points; the force is dissipated over the surface, and again the surface is subjected to hardly any more pressure than the bulk. As mentioned, it has been found that a concentration of points of about 50 per sq cm gives good results.

Other ways of texturing the surface of the platens are contemplated within the invention. For example, instead of knurled pyramidal points, the surface may be formed with triangular-shaped grooves, which leave sharp knife-edges between the grooves. In this case, the knife-edges should be about 2 mm apart. Alternatively, for example, the surface of the platen may be provided with small circular knife-edges. In another alternative example, small pins or spikes inserted into prepared holes in the platens can be provided.

In fact, the invention contemplates any system, pattern, texture, or arrangement of devices on the surface of the platen which exerts pressure at many locations on the surface of the embrittled tire as it passes through the platens. The locations are so arranged as to concentrate the pinch force into the locations.

The locations at which pressure is exerted on the surface of the tire would be too far apart if the material of the tire under treatment bottoms in the recesses between the locations. The locations would be too close together if the recesses between the locations are too small to receive the shattered fragments of the material.

Claims

CLAIM 1. Apparatus for breaking down pieces of a material, being material of the kind which becomes brittle at cryogenic temperatures;

the apparatus includes a pair of platens;

the apparatus includes a means for forcefully urging the platens in the direction towards each other;

the platens are arranged in cooperative opposition to each other for compressing therebetween the pieces of the material;

the apparatus includes a means for forcefully urging the platens together, and for driving the platens in motion, being motion of such a nature and direction of the platens with respect to each other as to create between the platens a progressively-advancing nip or pinch;

the apparatus includes means for placing the pieces of material in the advancing nip or pinch between the platens, and the nip or pinch, thus created, is of such a nature as to be effective, in use of the apparatus, to draw the material into, between, and through, the nip or pinch;

the apparatus includes a means for cooling the pieces of material, before the pieces pass through the nip or pinch, down to cryogenic temperatures at which the material becomes embrittled, and for maintaining the pieces at cryogenic temperatures in passing through the nip or pinch;

the platens include respective outer surfaces, being the surfaces of the platens which lie in contact with the piece of material when the piece is passing through the nip or pinch;

of the said outer surfaces, at least one of the surfaces is characterised as nodulated, in that the surface is substantially not smooth, but has nodulations having substantial crests and troughs;

and the means for forcefully urging the plattens together is effective to provide a pinch-force that is sufficient to crack and shatter a surface layer of the material, by the pinch-force, but not sufficient to crush the bulk of the material passing through the pinch.

CLAIM 2. Apparatus of claim 1, wherein:

the means for forcefully pinching the rollers together is effective to apply the pinch-force smoothly and evenly, in the sense that the pinch is characterised by a substantially smooth, even, gradually progressive application of force to the piece of material as the piece passes through the pinch;

the pinch is characterised as substantially free from hammering or pounding forces.

CLAIM 3. Apparatus of claim 1, wherein the height or depth between the crests and troughs of the nodulations is at least of the order of one-tenth of a millimetre.

CLAIM 4. Apparatus of claim 1, wherein the nodulations take the form of a knurled texture.

CLAIM 5. Apparatus of claim 1, wherein the nodulations comprise protruding points.

CLAIM 6. Apparatus of claim 5, wherein the protruding points are provided on the surface of the platen at a density of about 50 points per sq cm.

CLAIM 7. Apparatus of claim 6, wherein the protruding points are of pyramidal shape.

CLAIM 8. Apparatus of claim 7, wherein the points are arranged in regular rows, and have a pitch of about 2 mm.

CLAIM 9. Apparatus of claim 5, wherein the points are sharp to the extent that the apexes of the

points are no more than 0.5 sq mm in area.

CLAIM 10. Apparatus of claim 1, wherein the nodulations comprise alternating recesses and lands, the arrangement thereof being such that a surface layer of a piece of the composite is acted upon by the lands, and being such that broken fragments of the layer can enter the recesses.

CLAIM 11. Apparatus of claim 1, wherein the surface of the other platen is plain.

CLAIM 12. Apparatus of claim 1, wherein the surface of the other platen also is nodulated.

CLAIM 13. Apparatus of claim 1, in combination with pieces of the material, wherein the material is a composite which includes harder material embedded in a matrix of softer material, and the softer material is brittle at cryogenic temperatures.

CLAIM 14. Apparatus of claim 1, wherein the pair of platens comprises a pair of rollers, arranged for pinching or nipping between them the pieces of the material, and the apparatus includes a means for forcefully urging the rollers together, and for driving the rollers in rotation.

CLAIM 15. Apparatus of claim 14, wherein the roller surface of one of the rollers is formed with grooves, and the surface of the roller includes protruding lands between the grooves.

CLAIM 16. Apparatus of claim 15, wherein the roller is right cylindrical, and the grooves and lands are right cylindrical, and co-axial with the axis of the roller.

CLAIM 17. Apparatus of claim 16, wherein the grooves are about 4.7 mm wide and 4.7 mm deep, and the lands 6.4 mm wide.

CLAIM 18. Apparatus of claim 14, in combination with pieces of the composite, wherein the pieces of the material composite are in the form of coherent strips, being pieces of relatively large planar extent, and of relatively small thickness.

CLAIM 19. Apparatus of claim 18, wherein the depth of the grooves is deep enough that the shattered material of the surface layer of the strip can enter the groove, and not bottom in the groove.

CLAIM 20. Apparatus of claim 18, wherein the pitch of the grooves is roughly equal to the thickness of the strip.

CLAIM 21. Apparatus of claim 1, wherein the means for forcefully urging the rollers together provides a force of between 0.7 and 1.7 tonnes per linear cm of width of the piece of material.

CLAIM 22. Apparatus of claim 21, wherein the means for forcefully urging the rollers together provides a force of about 1.1 tonnes per linear cm of width of the piece of material.

CLAIM 23. Apparatus of claim 14, wherein:
the means for forcefully urging the rollers together comprises a means which is effective to allow the

rollers to move towards and away from each other;
and is effective to keep substantially constant the force urging the rollers together during such movement.

CLAIM 24. Apparatus of claim 23, wherein the means for forcefully urging the rollers together includes a hydraulic ram, and a source of hydraulic pressure, which is arranged to maintain pressure in the ram constant during the said movement of the rollers towards and away from each other.

CLAIM 25. Apparatus of claim 14, wherein the means for urging the rollers together is effective to urge the rollers together with a force that is large enough to cause a surface layer of the strip in contact with the lands to shatter, but is small enough that the remaining bulk thickness of the piece is substantially not shattered.

CLAIM 26. Apparatus of claim 14, wherein the apparatus includes several of the said pairs of rollers;
the pairs of the rollers are arranged successively, whereby the pieces of the material pass from the pinch of one pair of rollers to the pinch of the next pair of rollers in progressive sequence.

CLAIM 27. Apparatus of claim 18, wherein:
the rollers are arranged in progressive pinched-pairs, and the strips of material pass through from a first pinched-pair to a last pinched-pair;
and the nodulations on the surfaces of the rollers are relatively large and widely spaced at the first pair, and decrease progressively through the pairs, being relatively small and closely spaced at the last pair.

CLAIM 28. Apparatus of claim 27, wherein:
in respect of the first pair of rollers in the sequence of pairs the surfaces of both rollers are formed with protruding points and the surface of one of the rollers is formed with grooves;
and in respect of the last pair of rollers in the sequence, the surfaces of both rollers are formed with protruding points and neither of the rollers is formed with grooves.

CLAIM 29. Apparatus of claim 14, wherein the means for driving the rollers is such that the speed of the piece of material through the nip or pinch of the rollers is between 4 and 13 cm/sec.

CLAIM 30. Apparatus of claim 29, wherein the means for driving the rollers is such that the speed of the piece of material through the nip or pinch of the rollers is between 8 and 10 cm/sec.

CLAIM 31. Apparatus of claim 14, wherein the means for driving the rollers is such that the speed of the piece of material through the nip or pinch of the rollers gives rise to a sound that is characterised as a crisp, sharp, crackling sound.

CLAIM 32. Procedure for preparing composite material, wherein:
the procedure includes the step of providing an apparatus as claimed in claim 1;
the procedure includes the steps of operating the apparatus on tires, and of producing rubber crumb from that operation;
the procedure includes the step of treating the crumb thus produced with a suitable chemical

treatment, whereby the molecular cross-links, at least in the surfaces of the crumb, are broken down;

the procedure includes the steps of mixing the treated crumb with plastic material, and of re-polymerising the treated crumb in that mixture.

CLAIM 33. Procedure for preparing composite material, wherein:

the procedure includes the step of providing a quantity of rubber crumb, being crumb of the kind that has been derived from tires using the apparatus of claim 1;

the procedure includes the step of treating the said crumb with a suitable chemical treatment, whereby the molecular cross-links, at least in the surfaces of the crumb, are broken down;

the procedure includes the steps of mixing the treated crumb with plastic material, and of re-polymerising the treated crumb in that mixture.

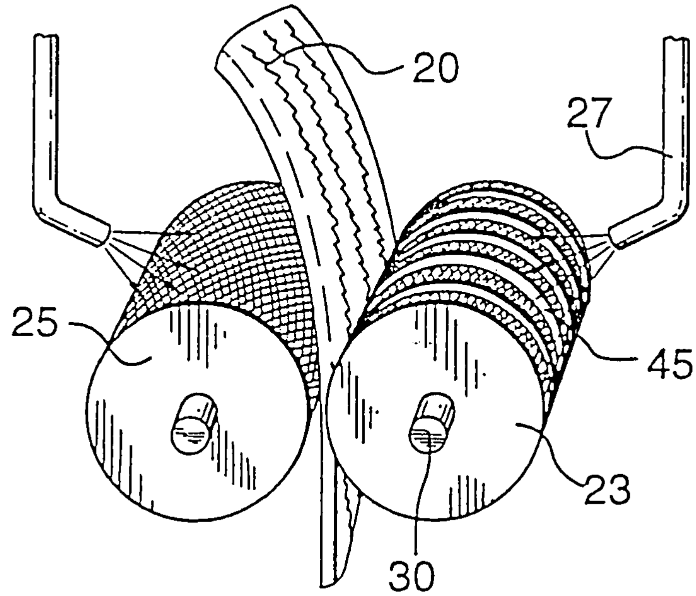

FIG.1.

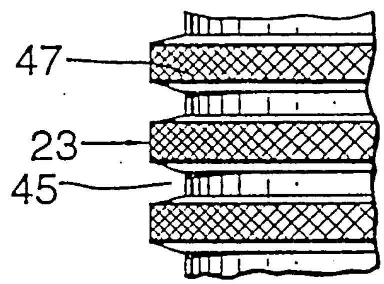

FIG.3.

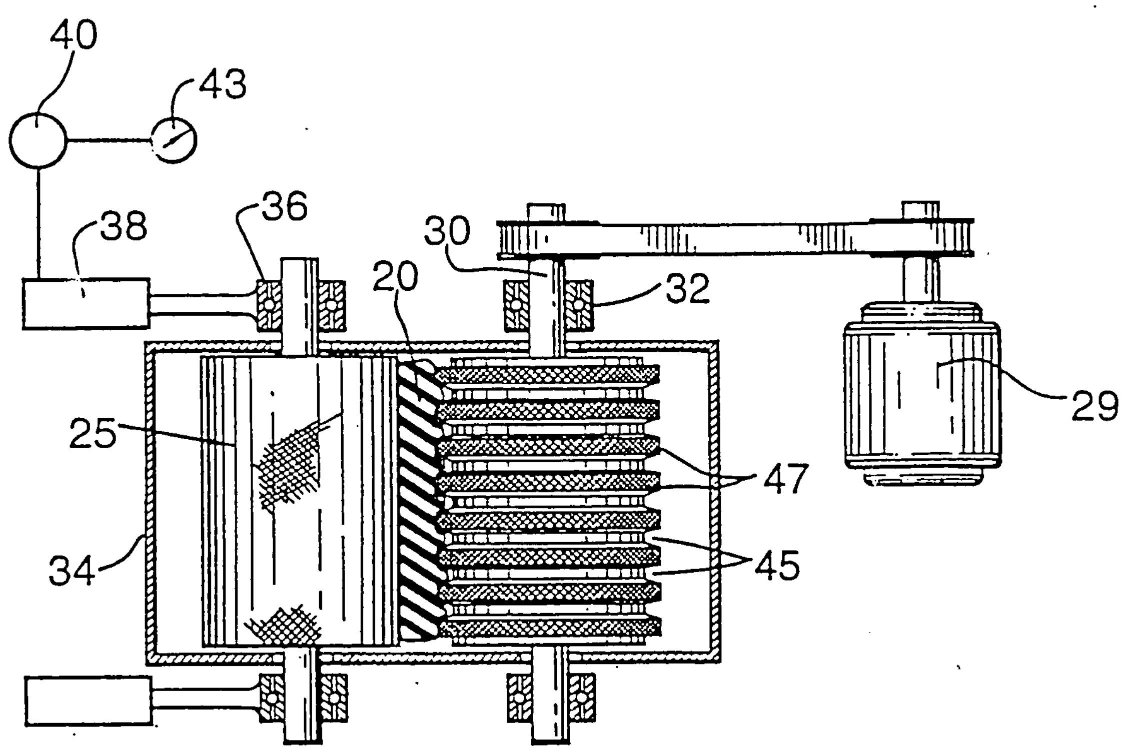

FIG.2.

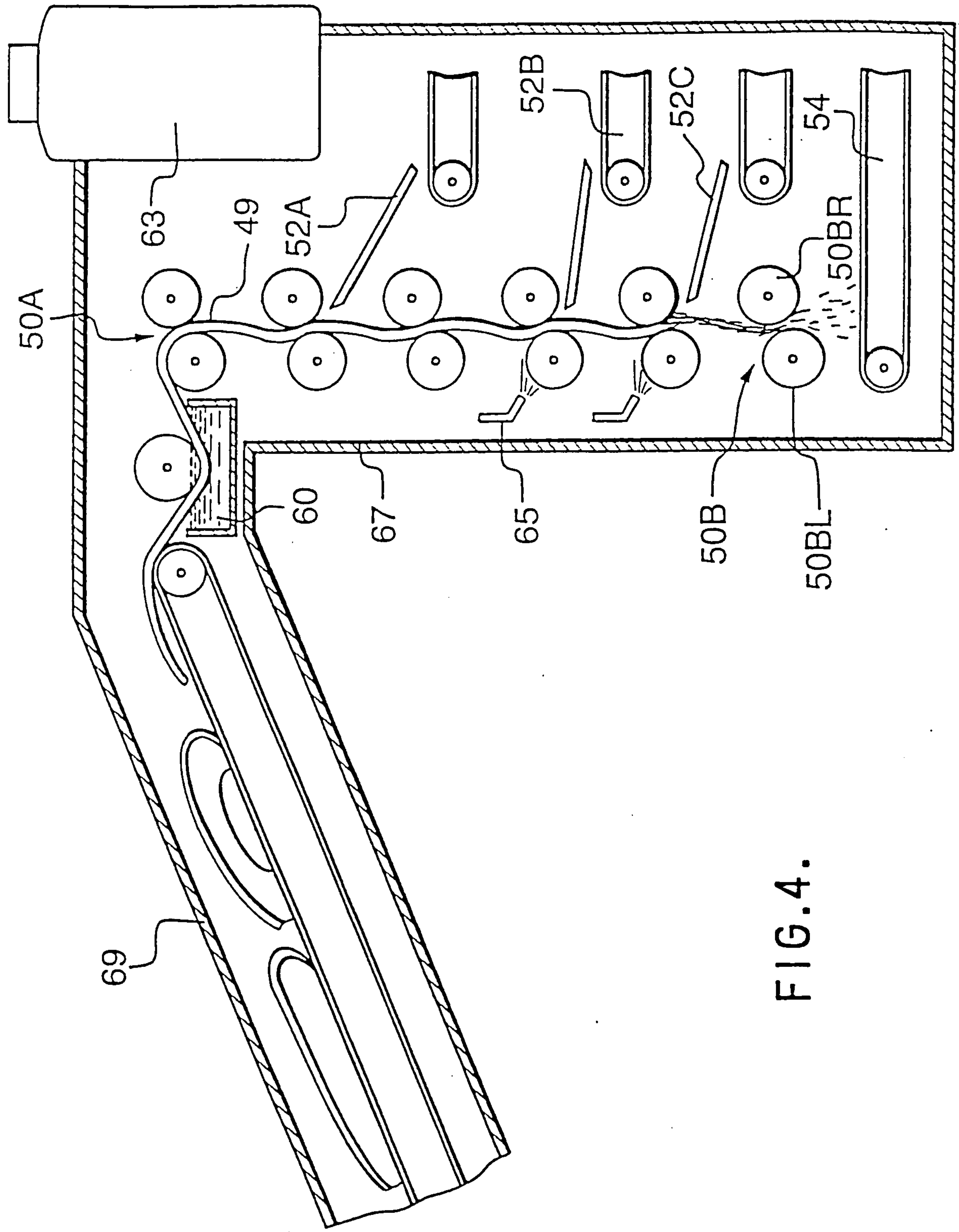

FIG.4.

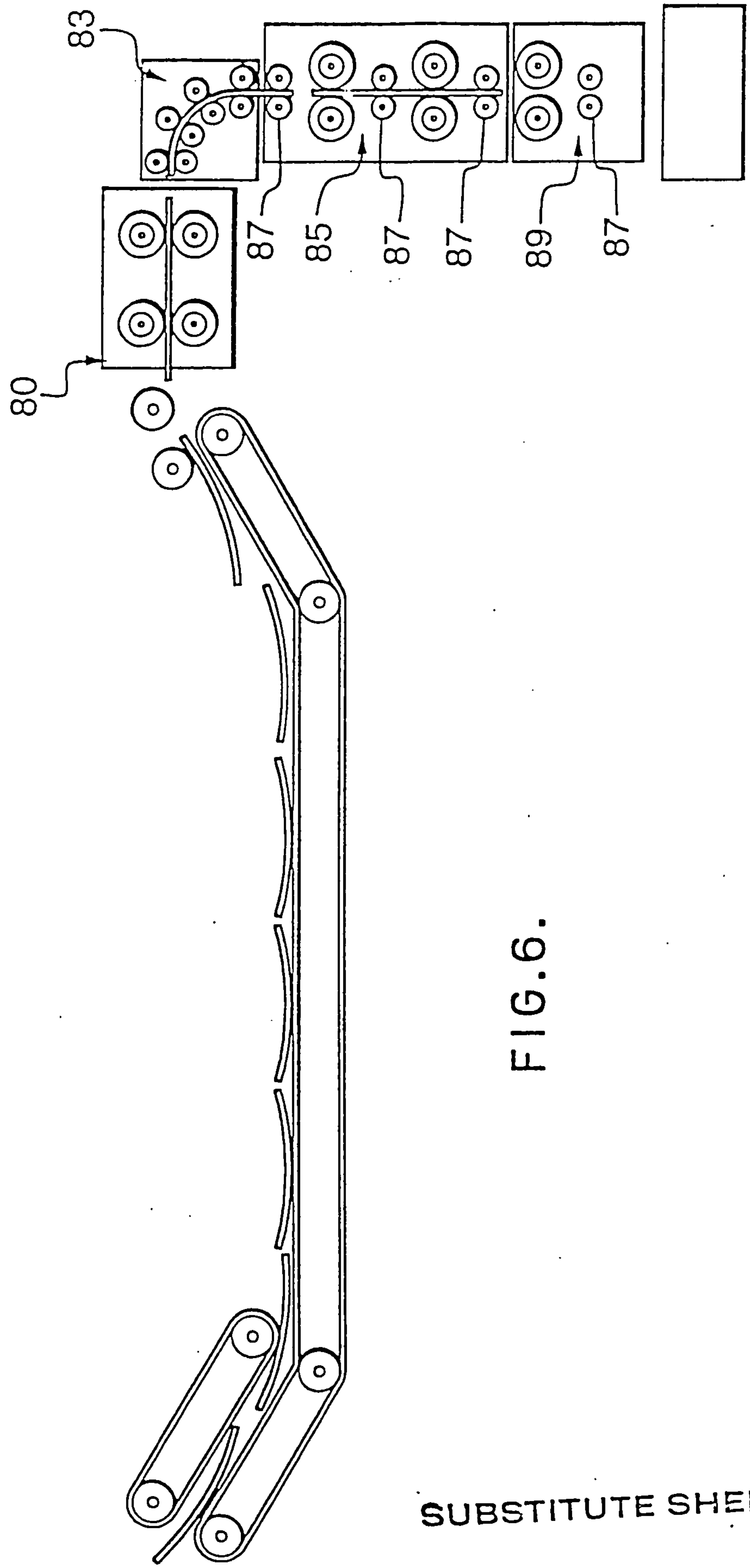

FIG.6.

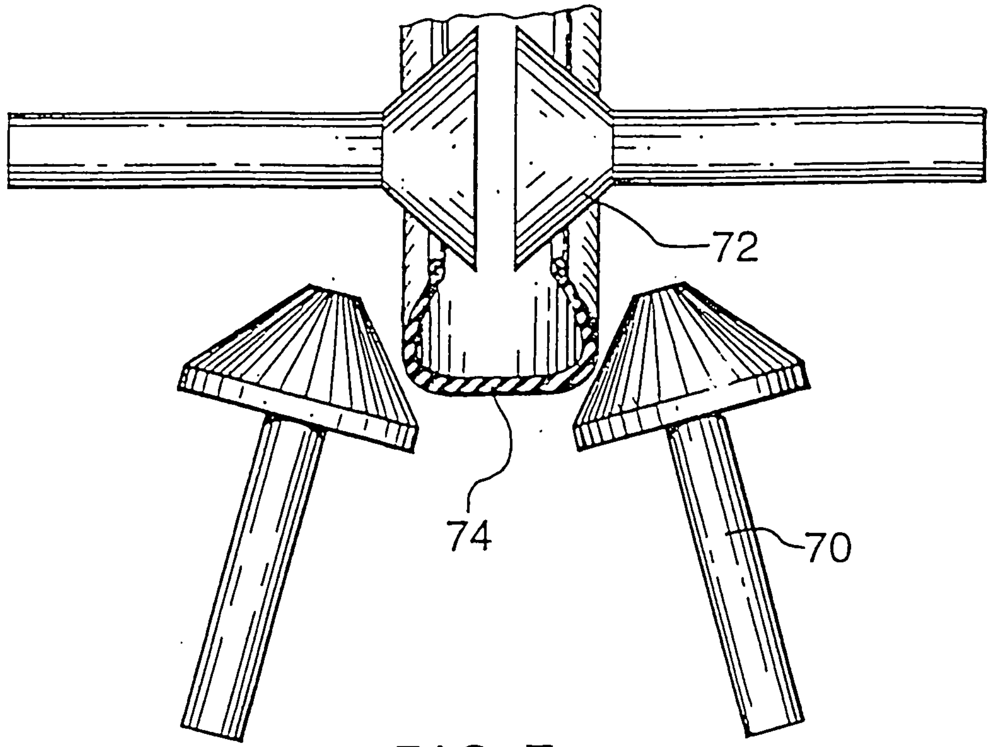

FIG.5.

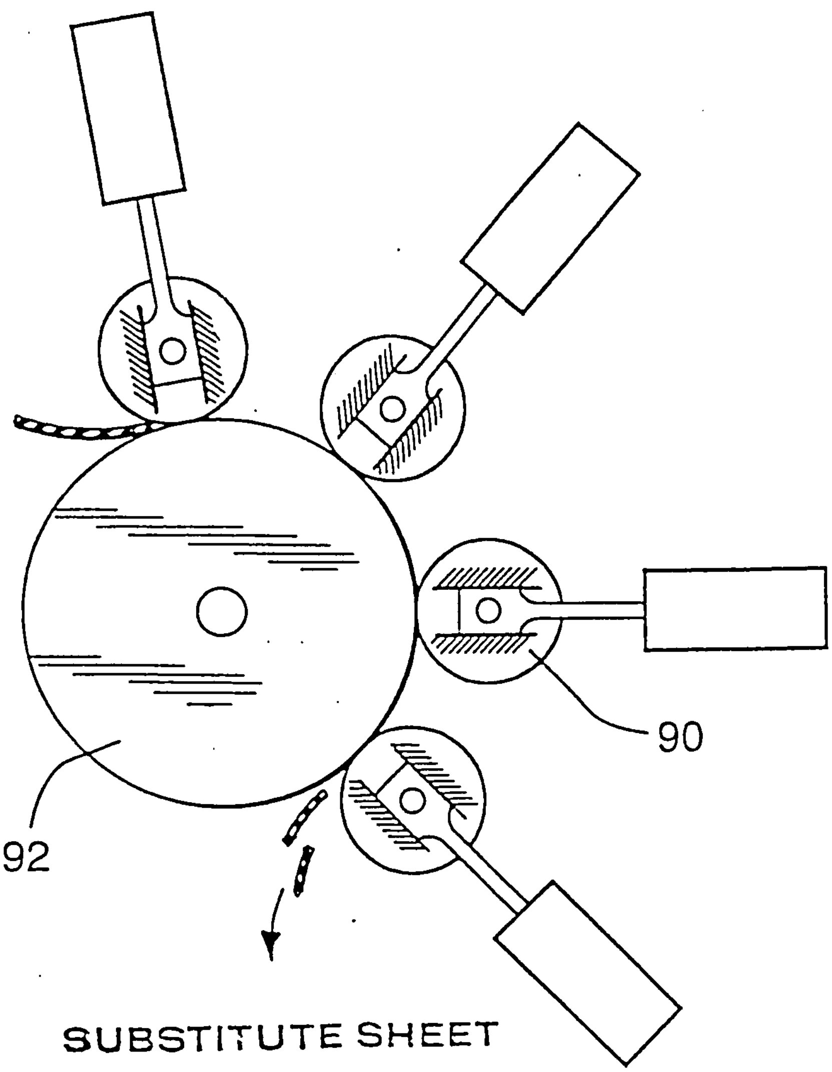

FIG.7.